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RESEARCH MEMORANDUM

INTERNAL PERFORMANCE OF SEVERAL TYPES OF JET-EXIT CONFIGURATIONS FOR SUPERSONIC TURBOJET AIRCRAFT

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NATIONAL ADVISORY COMMITTEE
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SUMMARY

Internal performance characteristics of several jet-exit configurations, which were investigated over a wide range of pressure ratios, are summarized to provide an over-all picture of jet-exit performance. These performance characteristics are presented with a view to providing data which would aid in selecting the most suitable jet-exit configurations for various supersonic aircraft. The jet-exit configurations discussed include a convergent nozzle, fixed convergent-divergent nozzles, an adjustable plug-type convergent-divergent nozzle, and jet ejectors.

At design pressure ratio the thrust ratios of an adjustable plug-type convergent-divergent nozzle and the conical ejectors with secondary flow were found to be comparable with those of fixed convergent-divergent nozzles. As the pressure ratio was increased above about 4, the thrust ratios of the convergent nozzle became increasingly lower than those of the other configurations. Matching the jet-exit performance to operating schedules of typical supersonic interceptors indicated that maximum jet-thrust ratios would be obtainable with a convergent-divergent nozzle or ejector having independently variable throat areas and expansion ratios.

INTRODUCTION

With the advent of supersonic turbojet aircraft, exhaust nozzles are required to operate over a range of pressure ratios from about 2 to 16. Basic thermodynamics as well as experiment (reference 1) have indicated that a convergent-divergent nozzle will provide maximum thrust at high-pressure-ratio conditions, although both theory and experiment have shown that such a nozzle is very inefficient when operating at low pressure ratios where it is greatly overexpanded. A variable-expansion-ratio nozzle would therefore be indicated for maximum thrust throughout a wide range of pressure ratios. A turbojet with afterburner would also require a nozzle which has variable throat area in addition to variable expansion ratio. Operating schedules requiring independent variation of throat area and expansion ratio greatly increase the complexity of the nozzle design.

Before proceeding with the design of such a complex nozzle, it is essential to determine the magnitude of the over-all performance gains attainable. Consideration must be given to the internal performance of various nozzle configurations in addition to such items as the size, weight, reliability, and compromise in external aerodynamics that might be imposed. The scope of this report is limited to consideration of the internal performance of several jet-exit configurations.

Experimental investigations have been conducted at the NACA Lewis laboratory to evaluate the internal performance of several types of jet exits. Performance of convergent and fixed convergent-divergent nozzles is reported in reference 1. The performance of a family of ejectors, which suggest themselves as possible jet-exit configurations because their thrust characteristics are similar to those of convergent-divergent nozzles, is presented in references 2 and 3. Performance data have also been obtained with an adjustable plug-type convergent-divergent nozzle. Data for these various jet-exit configurations are summarized herein for a range of operating conditions and give an over-all picture of jet-exit internal performance characteristics which will aid in selecting the most suitable jet-exit configurations for various supersonic aircraft. A final comparison is made by matching the performance characteristics of each configuration type to the operating schedule of a typical supersonic interceptor.

APPARATUS AND INSTRUMENTATION

Nozzle Facility

The nozzles were installed in a test chamber connected to the laboratory combustion air and altitude exhaust facilities as shown in figure 1. The nozzles were attached to a short section of pipe which was freely supported on flexure plates and isolated from the inlet duct by a labyrinth seal. This pipe was connected through a linkage to a calibrated balanced air-pressure diaphragm for measuring thrust.

Pressures and temperatures were measured at the stations indicated in figure 1. For the fixed nozzles a survey consisting of 30 total-pressure probes, 14 static-pressure probes, and 12 thermocouples was located ahead of the inlet at station 1 to measure the air flow. Static pressure at the throat of the fixed convergent-divergent nozzles (station 2) was measured by five trailing static-pressure tubes with two orifices each and by three wall static taps. In the adjustable plug-type nozzle a survey of 14 total-pressure probes, 8 static-pressure probes, 2 wall static taps, and 6 thermocouples were installed immediately upstream of the plug to measure the air flow. Static-pressure tubes were installed on the outside of all the nozzles to measure ambient-exhaust pressure in the plane of the nozzle exit. Sixteen wall static-pressure taps were located axially along the full length of the convergent-divergent nozzle having an expansion ratio of 2.65. The other two fixed convergent-divergent nozzles had nine static-pressure taps located between the nozzle throat and exit. The plug-type nozzle had 15 wall static taps located along the length of the outer shell and 10 wall static taps located along the plug.

Ejector Facility

A cross section of the facility used to evaluate ejector performance is shown in figure 2. The installation consisted of an inlet duct and jet nozzle supported within a concentric shroud which extended into an exhaust chamber. Primary and secondary air flows were introduced into the concentric pipes and passed through the ejector into the exhaust chamber, which was connected to the laboratory exhaust system. The ejector air-supply ducts were connected to the laboratory air system by flexible bellows and pivoted to a steel frame so that the axial thrust force would be transmitted to a balanced-pressure diaphragm. A labyrinth seal provided clearance between the ejector ducts and the exhaust chamber.

Primary and secondary total pressure and temperature were measured by single probes as indicated in figure 2. The pressure probes were located so as to measure the average values of total pressure in the primary and secondary passages. Location of the thermocouple probes was not critical since there was no temperature gradient. Exhaust pressure was measured by static-pressure taps located on the outside of the shroud in the plane of the exit. Primary and secondary air flows were measured by calibrated orifices.

Jet-Exit Configurations

The four fixed nozzles investigated, which are shown in figure 3, included one convergent and three convergent-divergent nozzles. The convergent-divergent nozzles were designed with expansion ratios of 1.39, 1.69, and 2.65. All four nozzles, which were of simple conical construction, had an inlet diameter of 21 inches and an inlet half-angle of 25°. Each convergent-divergent nozzle had an over-all length of 28 inches and an exit diameter of 13 inches. Consequently, the nozzles having higher expansion ratios had smaller throat diameters and higher divergence angles.

The adjustable plug-type convergent-divergent nozzle investigated is shown in figure 4. Inlet and exit diameters of the nozzle were 13 inches, and the throat area was varied by moving axially the external shell of the nozzle. It was characteristic of this nozzle that for any given throat area the nozzle had only one expansion ratio. Consequently, moving the external shell over its entire range of travel to vary nozzle-throat area provided an attendant variation in expansion ratio from 1.5 to 2.5.

Ejector configurations investigated were of the convergent type illustrated in figure 5. The primary nozzle had a half-angle of 8°, an inlet diameter of 5 inches, and an exit diameter of 4 inches. The shroud also had a half-angle of 8° and an inlet diameter of 10 inches. Ejector configurations which were investigated are listed in the following tabulation:

Expansion ratio A_s/A_n	Nominal spacing ratios S/D_n
1.13	0.2, .4, .6, .8, 1.0
1.21	0.4, .8, 1.2, 1.6
1.42	0.4, .8, 1.2, 1.6
1.96	0.4, .8, 1.2, 1.6

PROCEDURE

Nozzle performance data were obtained over a range of pressure ratios at several different air flows. For each series of data the nozzle-inlet pressure and temperature were established and the pressure ratio was varied by lowering the exhaust pressure. Pressure ratio was varied from 1.28 to 14.6 for the convergent nozzle and from a value of about 1.25 to at least the design pressure ratio for the fixed convergent-divergent nozzles and for each of several expansion-ratio settings of the variable nozzle. With the size of the nozzles used in the investigation, it was necessary to heat the nozzle-inlet air to about 910° R in order to cover the desired pressure-ratio range with the laboratory facilities. Early in the investigation, nozzle wall pressure distributions were checked for evidence of condensation shock effects by using both wet and dry air preheated to various temperatures (reference 1). Generalization of the pressures along the nozzles for a range of inlet-air temperatures indicated the absence of condensation shocks of such strength as to affect the flow along the nozzle walls.

Performance of each ejector configuration was investigated over a range of nozzle pressure ratios from about 1 to 10 with zero secondary flow and with the secondary flows corresponding to secondary pressure ratios up to 4. For each series of data the secondary pressure ratio was held constant while the nozzle pressure ratio was increased by raising nozzle-inlet pressure to its maximum value. After reaching the maximum nozzle-inlet pressure, the nozzle pressure ratio was further raised by reducing the exhaust-chamber pressure to its minimum value. Both the primary and the secondary air were maintained at a constant temperature of about 540° R. The use of air with a dew point of 440° R was found sufficient to eliminate effects of condensation shock in the ejector (reference 4).

The thrust ratio used for the nozzle data is defined as the ratio of measured jet thrust to ideal isentropic thrust. So that the thrust ratio of ejectors would be directly comparable to that of the nozzles, it is defined as the ratio of measured jet thrust to the sum of the ideal isentropic thrusts of the primary and secondary flows. Measured thrusts were obtained from force measurements on the thrust systems. The isentropic thrust was defined as the product of mass flow and velocity at the exit of a convergent-divergent nozzle with the flow completely expanded to ambient exhaust pressure. Isentropic thrusts were computed with use of the ambient exhaust pressure and the measured mass flow, total pressure, and temperature at the nozzle inlet and in the case of the ejector in the secondary air passage immediately ahead of the nozzle.

DISCUSSION OF RESULTS

Performance of Several Jet-Exit Configurations

It should be pointed out that the performance of the exhaust nozzle is as important as that of the other engine components, and it becomes increasingly important as flight Mach number is increased. For example, the jet-thrust losses encountered at high pressure ratios corresponding to supersonic flight speeds will result in net propulsive thrust losses $1\frac{1}{2}$ to 2 times as much as the jet-thrust losses. This magnification of net-thrust losses is due to the fact that the free-stream momentum of the engine air, which must be subtracted from jet thrust to obtain net thrust, becomes a large fraction of the jet thrust at supersonic flight speeds. Resultant losses in net thrust at these speeds may completely offset any engine performance gains resulting from improvements in other components of the engine.

In order to establish a datum for the discussion of exhaust-nozzle performance, the variation of thrust ratio with nozzle pressure ratio is presented for a simple convergent conical exhaust nozzle in figure 6, which was taken from reference 1. The general trend of the data is such that the thrust ratio gradually decreased as the nozzle pressure ratio was raised. Values of thrust ratio were reasonably high, greater than 0.965, up to a pressure ratio of 4.0; however, at a pressure ratio of 15 the thrust ratio had decreased to a value of about 0.9.

The types of variable-area exhaust nozzles currently in use on turbojet afterburners are convergent clamshell or iris nozzles. Although data have not been obtained at high pressure ratios for these types of nozzles, the thrust ratios presented in figure 6 for the convergent conical nozzle are considered representative of those obtainable with well-designed clamshell or iris nozzles. Some substantiation is afforded this statement by the agreement of these thrust ratios with those included in reference 5 for a clamshell nozzle investigated up to a pressure ratio of 3.5.

In order to compare the performance of the convergent nozzle with that of the convergent-divergent nozzles, data are presented in figure 7 for several fixed convergent-divergent nozzles. Data for the 1.13-expansion-ratio nozzle were obtained from reference 6, and the remainder were obtained from reference 1. These fixed convergent-divergent nozzles, which in themselves would have a very limited application to turbojet aircraft, were investigated to evaluate the internal performance of this type of nozzle at off-design as well as at design conditions. It is believed that such data are valuable to provide a basis for subsequent variable-area designs. Near design pressure ratio, the thrust ratios for the convergent-divergent nozzles were appreciably higher than were those of the convergent nozzle, except at pressure ratios below 4 where they were about equal. For example, at a pressure ratio of 15, the thrust ratio for the convergent-divergent nozzle was 0.95 as compared with 0.90 for the convergent nozzle. At pressure ratios well below the design value, the performance of the convergent-divergent nozzles was, of course, much poorer than that of the convergent nozzle. It should be noted that as design pressure ratio was increased there was a gradual downward trend in the thrust-ratio maximums for the convergent-divergent nozzles. As illustrated in figure 3, an increase in nozzle expansion ratio was accompanied by a slight increase in expansion angle. The downward trend of thrust maximums with increased pressure ratio is attributed to the increase in expansion angle. Data obtained subsequently at an expansion ratio of 1.39 with divergence angles from about $3\frac{1}{2}^{\circ}$ to 12° have shown that at the design pressure ratio there was a similar decrease in thrust ratio as the divergence angle was increased.

Another type of convergent-divergent nozzle which was investigated was the adjustable plug-type nozzle. Performance data obtained with this type of nozzle are presented in figure 8. Although this nozzle did not have independently variable throat and exit areas, as would be required for optimum turbojet application, the internal performance obtained indicates the suitability of the center plug type of adjustable convergent-divergent nozzles from the aspect of efficient internal performance. The slightly higher thrust ratios obtained with the adjustable nozzle at high pressure ratios are attributed to the smaller divergence angle on the adjustable nozzle than on the fixed nozzles. The performance comparison between the fixed and adjustable nozzles is significant in that it indicates performance equal to that of fixed conical convergent-divergent nozzles can be obtained with a plug-type variable-area convergent-divergent nozzle formed by simple conical shapes.

The jet ejector is suggested as one promising type of jet exit for supersonic turbojet aircraft, because the thrust characteristics behave in a manner similar to that of the convergent-divergent nozzle. This type of configuration would also lend itself readily to variable-area geometry by using an iris-type nozzle and iris shroud, which could be independently actuated to provide the throat- and exit-area control compatable with the selected flight plan.

The thrust ratios of a family of conical ejectors with expansion ratios from 1.13 to 1.96 and a range of spacing ratios are shown in figure 9 for no secondary flow. These data as well as the succeeding ejector data presented were obtained from references 2 and 3. Comparison of these data with the data of figures 7 and 8 indicates the similarity previously mentioned between the ejector and convergent-divergent nozzle performance. The thrust ratios dropped to relatively low values when the ejector was over expanded, but increased to a value of about 0.94 at design pressure ratio and optimum spacing ratio. High thrust ratios obtained at very low pressure ratios for some configurations result from failure of the jet to completely fill the shroud. At these conditions the exit merely behaves as a convergent nozzle instead of an ejector.

Thrust performance of ejectors with secondary flows of 3 and 7 percent of the primary flow is shown in figures 10 and 11, respectively. As stated in the section PROCEDURE, to enable direct comparison of ejector performance with secondary flow to that of the previously discussed configurations, the thrust ratio is defined as the measured jet thrust divided by the sum of the ideal isentropic thrusts of the primary and secondary jets. Since these data were obtained with primary and secondary temperatures equal to about 540° R, the 3- and 7-percent secondary flows referred to here would correspond to secondary flows of about 7 and 16 percent, respectively, for an afterburner with an exhaust-gas temperature of 3500° R and secondary temperature of about 700° R. Another point which bears mention is that to maintain the secondary flow at a constant percent of the primary flow while the nozzle pressure ratio is being increased requires an attendant increase in secondary pressure ratio. These required variations in secondary pressure ratio for the ejector data presented herein may be obtained directly from references 2 and 3.

Addition of secondary flow to the ejector cushioned the expansion of the jet in such a manner as to greatly reduce the variation of thrust ratio with nozzle pressure ratio. A secondary flow of 7 percent completely eliminated the severe thrust losses experienced with the large-expansion-ratio ejectors having no secondary flow. In some cases the addition of the secondary air also reduced the effect of spacing ratio. It is observed that increasing the secondary flow from 0 to 7 percent raised the maximum thrust level by 2 to 4 percent, resulting in maximum thrust ratios approximately the same as for the convergent-divergent nozzles. It is of interest to note the comparison of the thrust characteristics of cylindrical ejectors with those shown for the conical ejectors. Data as yet not published for a family of cylindrical ejectors indicate that the thrust ratios are from about zero to 0.05 higher than the conical ejector values.

The sensitivity of the ejector thrust ratio to variations in expansion ratio is indicated in figure 12 for a spacing ratio of 0.8, the one which gave maximum thrust at most conditions. Except for the case of no secondary flow at a nozzle pressure ratio of 3.0, the maximum thrust variation for any condition did not exceed 3 percent over the range of expansion ratios. For expansion ratios between about 1.4 and 1.6, the thrust-ratio variation with pressure ratio did not exceed $1\frac{1}{2}$ percent for operation with secondary flows of 3 and 7 percent. In view of this characteristic, several modes of operating with the ejector suggest themselves at this point. The simplest method would be to select the ejector diameter for the design condition and accept a thrust penalty for off-design operation. Another method would be to use a two-position shroud, which opened with the variable-area primary nozzle for afterburner operation and closed for nonafterburner operation. Only minor thrust penalties would be suffered by the changes in expansion ratio resulting from the small variations of nozzle area required to modulate thrust near the cruise or design Mach number conditions. The most refined technique would be to continually vary shroud-exit area with nozzle area to provide maximum thrust. The suitability and schedules of each of these schemes would be limited by their ability to provide the proper amount of secondary flow for cooling purposes at all conditions.

The effect of spacing ratio on ejector performance is shown in figure 13 for three pressure ratios with the expansion ratio held fixed at a value of 1.46, the value for which maximum thrust was obtained for most conditions. These data indicate that when the secondary flow is as high as 7 percent the spacing ratio may be varied from 0.6 to 1.2, corresponding to variations in nozzle area of as much as two to one for a fixed shroud length, with only a 2-percent variation in thrust ratio. For the same range of spacing ratios the thrust variations for 0- and 3-percent secondary flow amount to as much as 8 percent. Consequently, to maintain near maximum thrust with small amounts of secondary flow, axial movement of the shroud may be necessary as nozzle area is varied so as to maintain the spacing ratio nearly constant.

This brief examination of ejector performance has indicated the promise offered by the ejector as an efficient jet-exit configuration. Whether the diameter of the shroud and axial position may be fixed or should be varied must be determined for each individual installation by matching the thrust and pumping characteristics with the scheduled operating conditions of the aircraft.

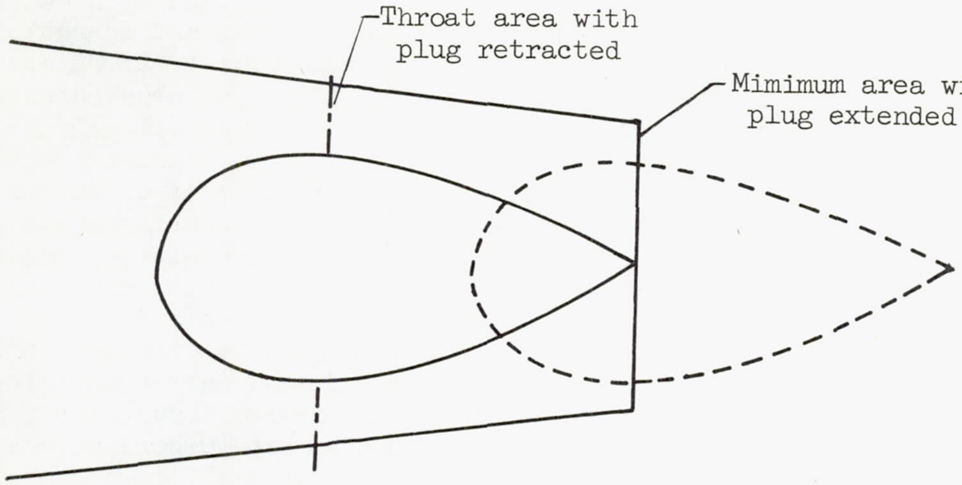
Matching Adjustable Jet Exits to Supersonic Aircraft

After reviewing the performance of several isolated jet-exit configurations, the next logical step is to determine how the performance of these configurations matches the operating schedules of supersonic turbojet engine installations. To illustrate this matching, two typical supersonic interceptor operating schedules were selected. One was for an interceptor designed for operation at a flight Mach number of 1.5 and the other was for operation at a flight Mach number of 2.0. The resultant schedules of nozzle-throat area, expansion ratio, exhaust-gas temperature, and nozzle pressure ratio are shown as a function of flight Mach number in figure 14. The schedules selected specify nonafterburning cruise at a Mach number of 0.8, acceleration to the design Mach number with an afterburner exhaust-gas temperature of 3500° R, and operation at the design Mach numbers with an exhaust-gas temperature of 2500° R. These schedules require large variations in both nozzle-throat area and expansion ratio over the range of operation.

The jet-thrust ratios are compared in figure 15 for a convergent nozzle, maximum of convergent-divergent nozzles (representing continuously variable nozzle), plug-type convergent-divergent nozzle, and ejector. It was assumed for the ejector case that the secondary air required for afterburner cooling was about 0.07 of the primary flow. As mentioned previously in the DISCUSSION OF RESULTS, this secondary flow with afterburning would correspond to a ratio of secondary-to-primary flows of 0.03 for the cold jet. The extrapolation required to obtain plug-nozzle values for conditions between flight Mach numbers of 0.8 and 1.5 was based on fixed-nozzle data.

Although the thrust ratio of the convergent nozzle was 0.97 at a Mach number of 0.8, it dropped to 0.955 at the Mach number 1.5 condition and further decreased to 0.93 at a Mach number of 2.0. In contrast, the maximum for the family of fixed convergent-divergent nozzles indicates that a variable nozzle of this type would provide a relatively constant thrust ratio, varying only from 0.97 at a Mach number of 0.8 to 0.955 at a Mach number of 2.0.

The adjustable plug nozzle provided essentially the same thrust ratios at the supersonic design Mach numbers as the conical convergent-divergent nozzles. However, as the Mach number was reduced below the design value, the thrust ratio decreased. The value at the subsonic cruise condition was only 0.85 for the Mach number 1.5 design and 0.75 for the Mach number 2.0 design. The abrupt irregularities in thrust ratio at the subsonic cruise and the 1.5 Mach number design conditions resulted from the large changes in expansion ratio accompanying the required variations in nozzle-throat area at these conditions. Examination of the data for this nozzle in figure 8 reveals the possibility that, if the nozzle design were selected for operation with an underexpanded flow at the design condition, the thrust ratio at the design condition would be compromised only slightly, and the thrust ratio at the subsonic cruise condition, although still very low, would be raised by as much as 6 to 8 percent. The undesirable qualities of the convergent-divergent adjustable plug-type nozzle considered herein arise from the reduction in expansion ratio as the nozzle-throat area was increased. The variation in this manner is opposite to that required for most conventional supersonic turbojet flight plans. A plug-type nozzle, which provided an increase in expansion ratio with throat area as shown in the following sketch, may be more adaptable to the operating schedule of a turbojet with afterburning.



A single fixed convergent-divergent nozzle selected for the supersonic design conditions of figure 14 would provide much lower thrust below design Mach number than the adjustable plug-type nozzle. The throat area would be too small for operation at an exhaust-gas temperature of 3500° R and much too large to obtain rated turbine-outlet temperature at the subsonic cruise condition. Such a nozzle would be applicable only in the case of a supersonic missile designed to operate over a very limited range of Mach numbers and exhaust-gas temperatures.

The thrust ratios presented for the ejector represent the maximums for a configuration with continuously variable throat area, exit area, and shroud length, and a secondary-to-primary flow ratio of 0.03 (fig. 10). The thrust ratio varied from about 0.98 at a Mach number of 0.8 to 0.97 at a Mach number of 1.5 and 0.96 at a Mach number of 2.0. These values correspond very closely with the maximums for the several fixed convergent-divergent nozzles.

Comparison of the various exit configurations showed that at flight Mach numbers of 1.5 to 2.0 a well-designed convergent-divergent nozzle on an afterburning turbojet engine will give a 2- to 3-percent gain in jet thrust, corresponding to a 4- to 6-percent gain in net thrust, over that obtainable with a convergent nozzle. It is apparent from the plug-nozzle performance that independently variable throat and exit areas are required to maintain high thrust ratios at all operating conditions. If the configuration selected requires a significant amount of cooling air, the ejector appears to be a good choice for an efficient exit configuration.

CONCLUDING REMARKS

A plug-type adjustable convergent-divergent nozzle and conical ejectors with secondary flow were found to provide jet-thrust ratios comparable with those of fixed convergent-divergent nozzles at design pressure ratio, whereas the thrust ratios for the convergent nozzle decreased rapidly above a pressure ratio of about 4.0. As the ejector secondary flow was increased, the thrust ratio of the ejector became approximately equal to that of the convergent-divergent nozzles and much less sensitive to variations in nozzle pressure ratio than the convergent-divergent nozzles.

When the performance of the exit configurations was matched to typical supersonic interceptor operating schedules, it was noted that a significant thrust loss was suffered with a convergent nozzle at supersonic Mach numbers. High thrust losses were also experienced with the adjustable plug-type convergent-divergent nozzle at the subsonic cruise condition. The thrust ratio was relatively constant throughout the flight Mach number range for the several fixed convergent-divergent nozzles simulating a continuously variable nozzle. Data for a series of ejectors with secondary flow indicated that throughout the range of flight Mach numbers considered a continuously variable ejector would provide thrust ratios approximately equal to those for the convergent-divergent nozzle. As a result of these characteristics, the variable ejector offers promise as one type of variable-area jet exit with reasonably good thrust characteristics for supersonic turbojet aircraft installations requiring secondary cooling flow.

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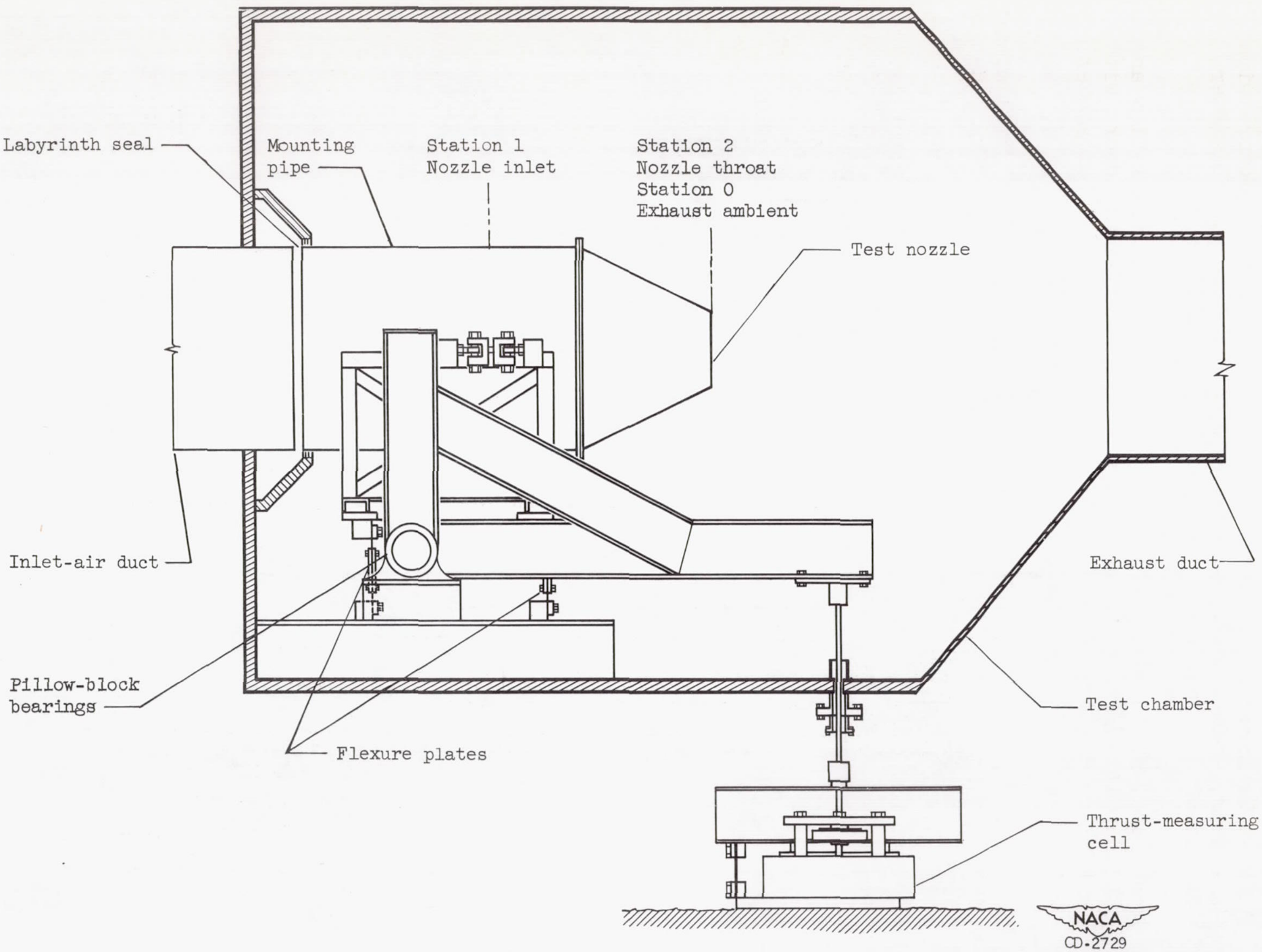


Figure 1. - Nozzle test facility.

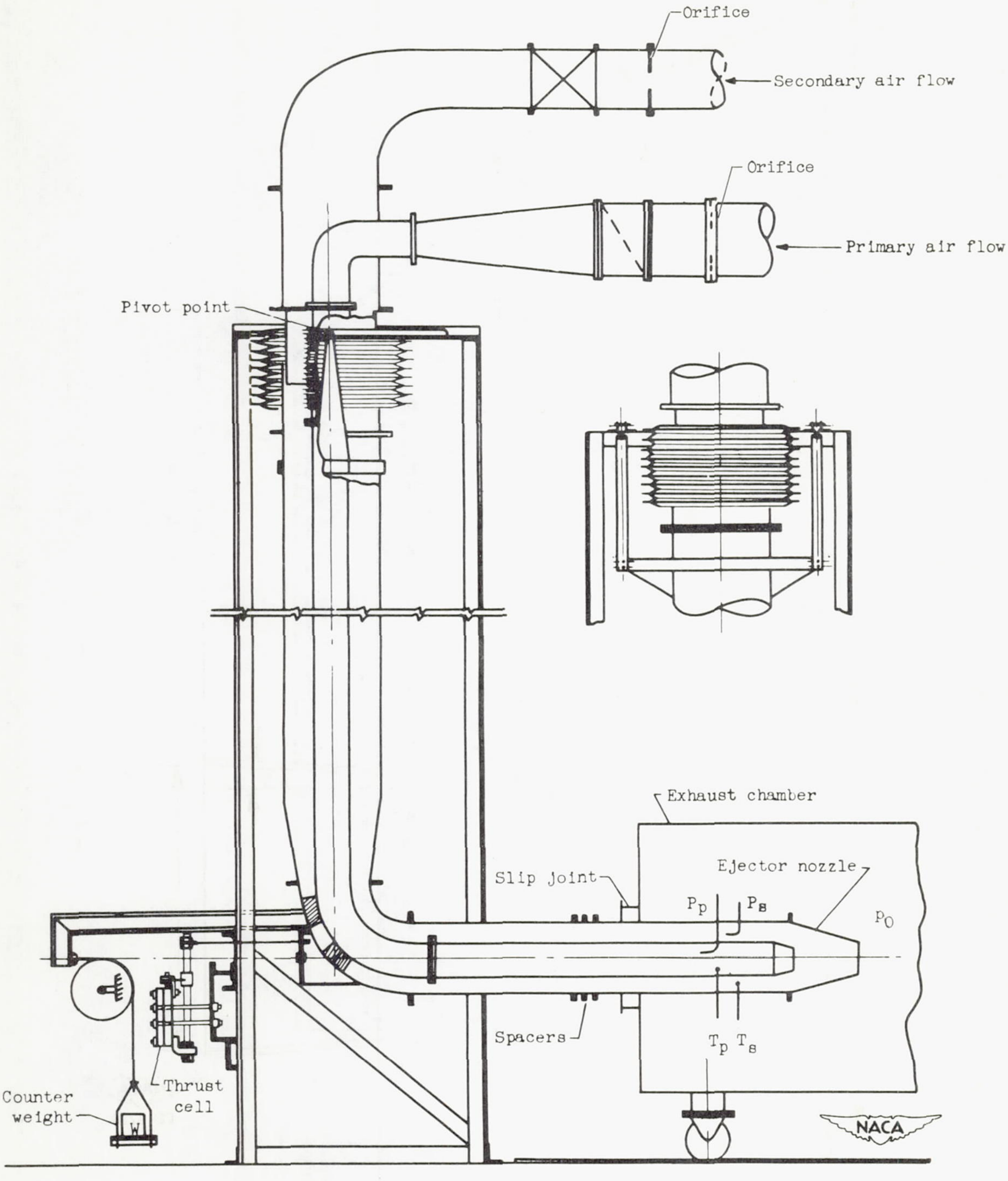
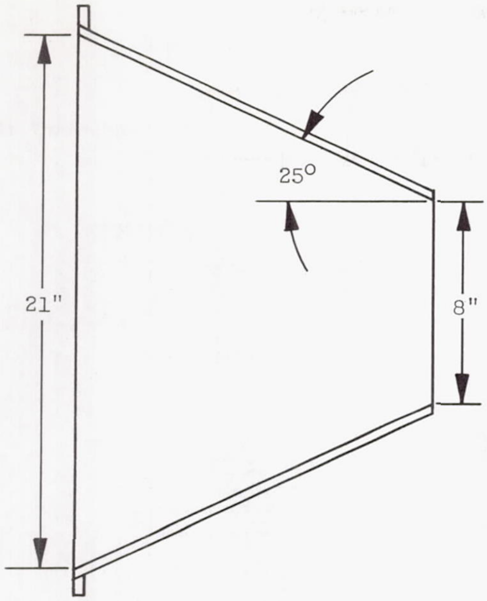
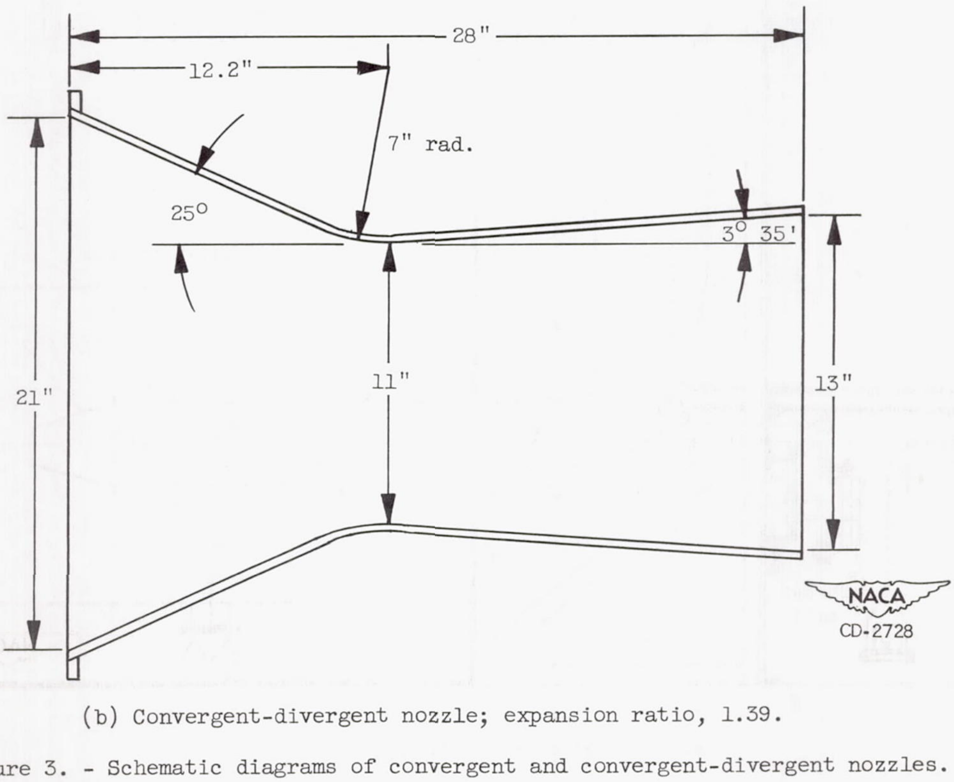


Figure 2. - Ejector test facility.

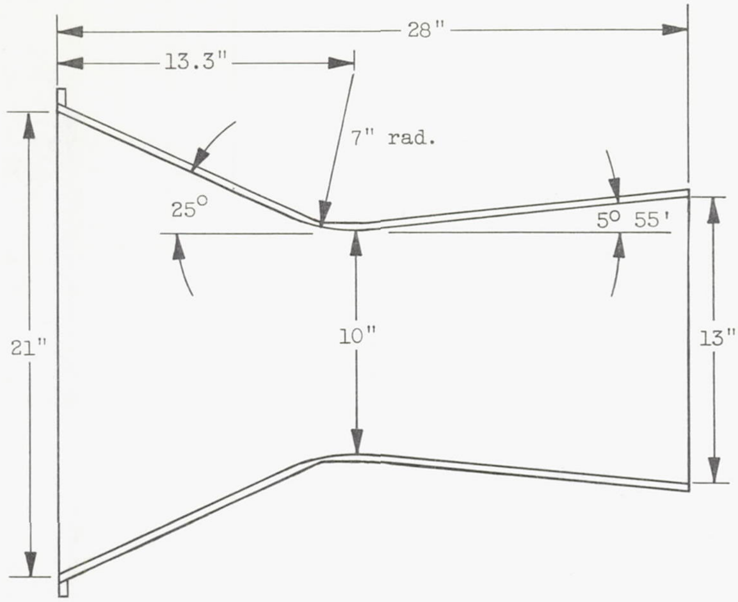


(a) Convergent nozzle.

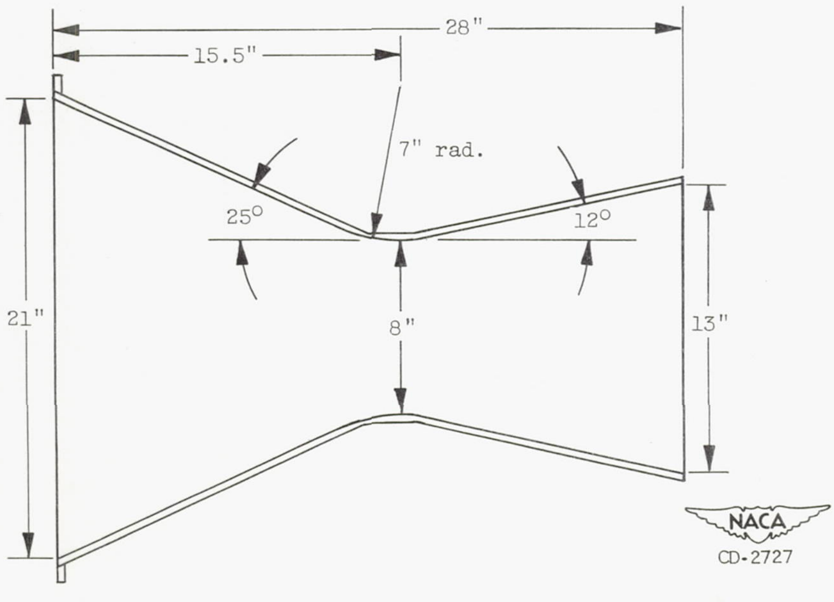


(b) Convergent-divergent nozzle; expansion ratio, 1.39.

Figure 3. - Schematic diagrams of convergent and convergent-divergent nozzles.



(c) Convergent-divergent nozzle; expansion ratio, 1.69.



(d) Convergent-divergent nozzle; expansion ratio, 2.65.

Figure 3. - Concluded. Schematic diagrams of convergent and convergent-divergent nozzles.

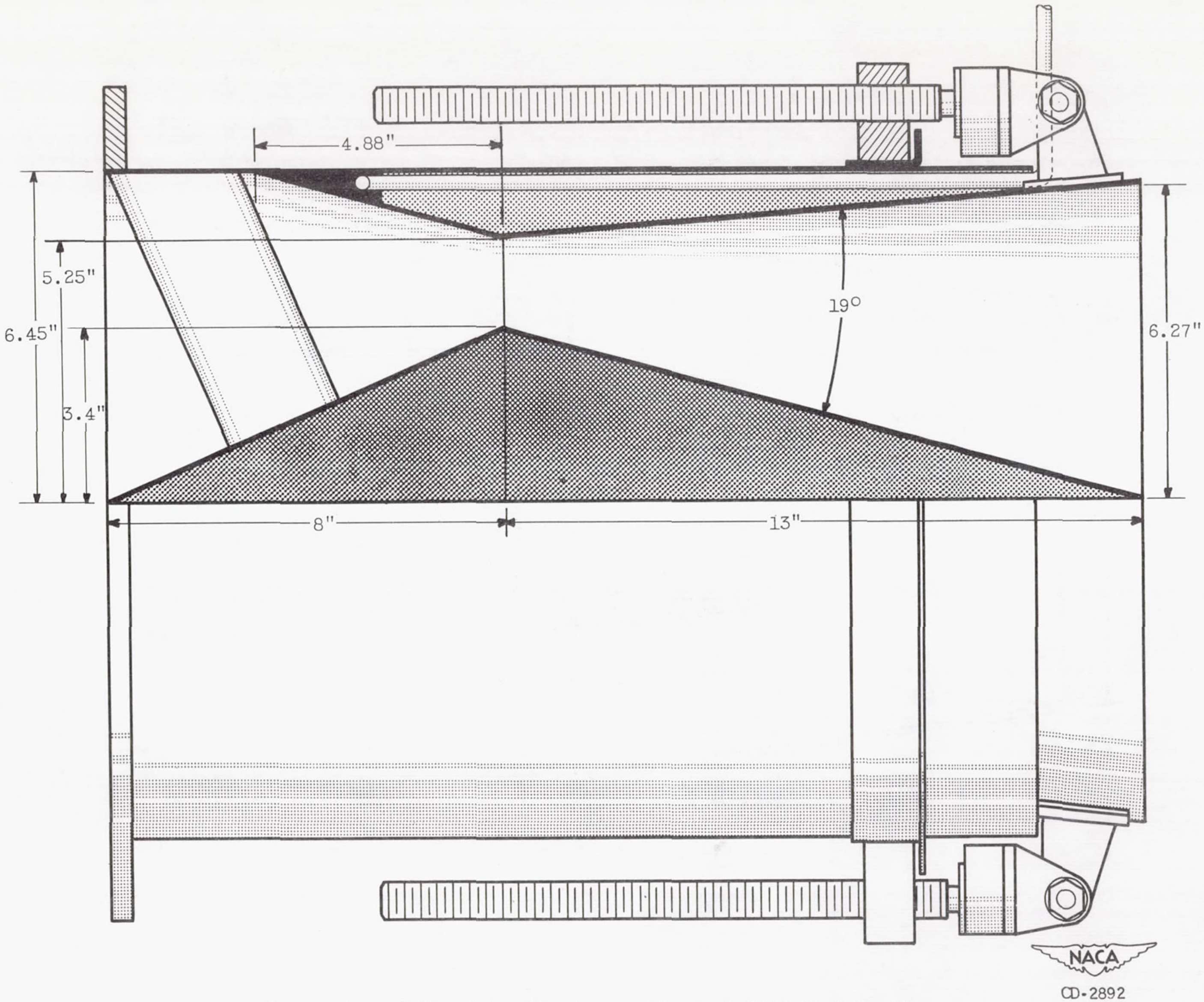


Figure 4. - Adjustable plug-type convergent-divergent nozzle.

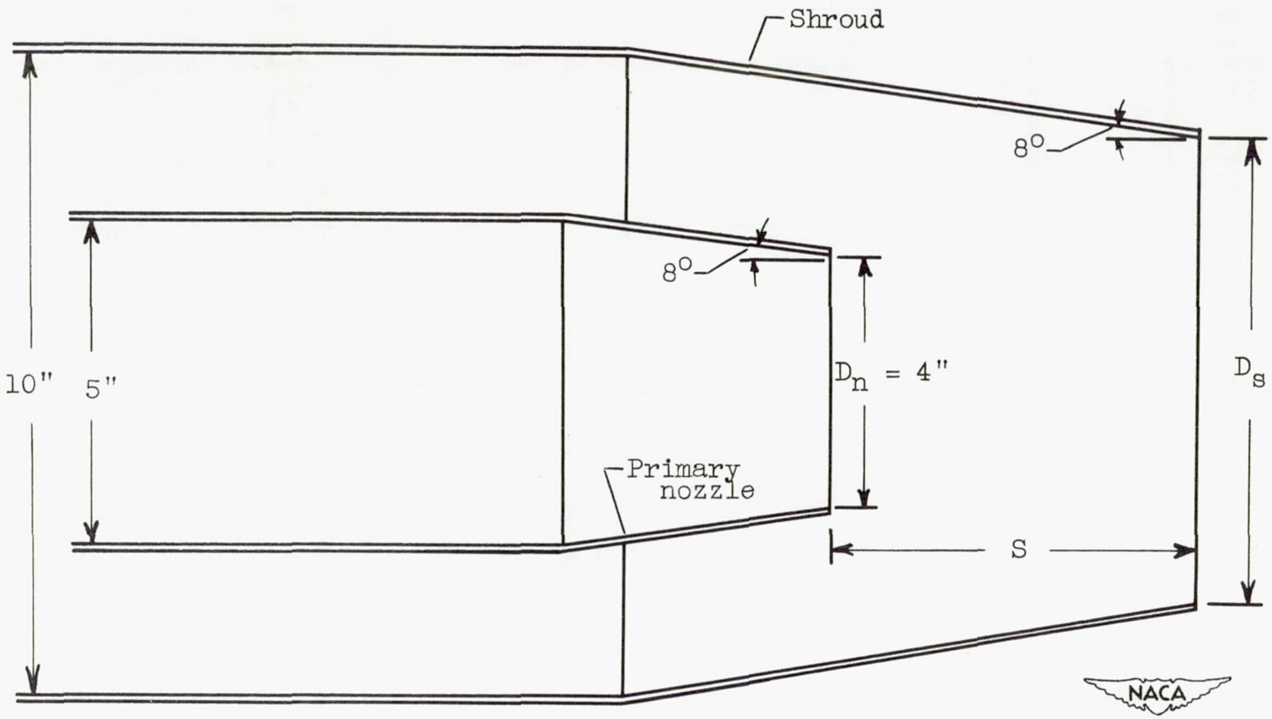


Figure 5. - Schematic diagram of convergent-type ejectors. D_n, nozzle diameter; D_s, shroud-exit diameter; S, shroud length.

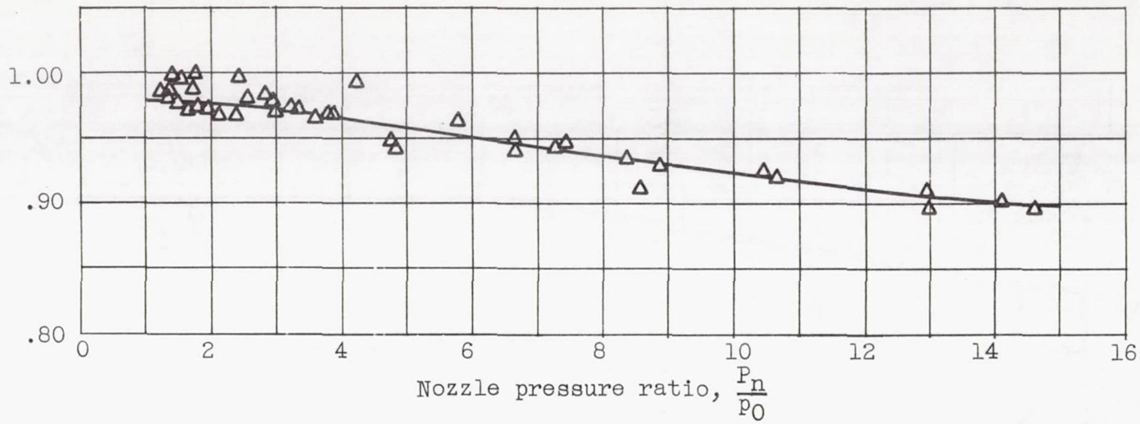


Figure 6. - Thrust characteristics of conical convergent nozzle.

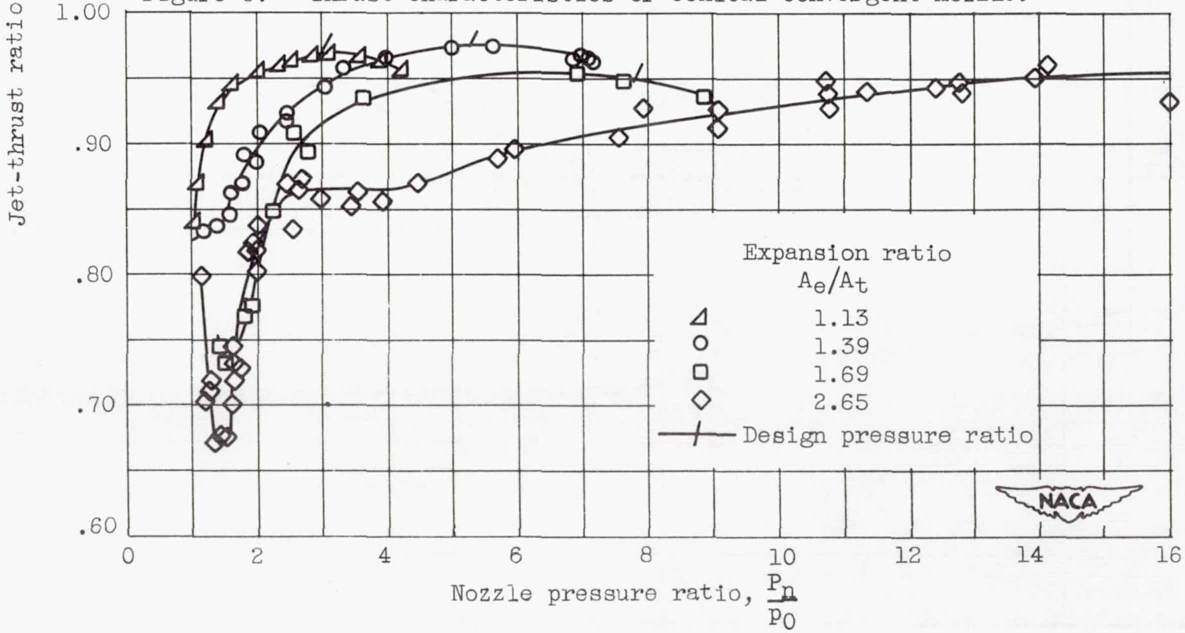


Figure 7. - Thrust characteristics of several fixed convergent-divergent nozzles.

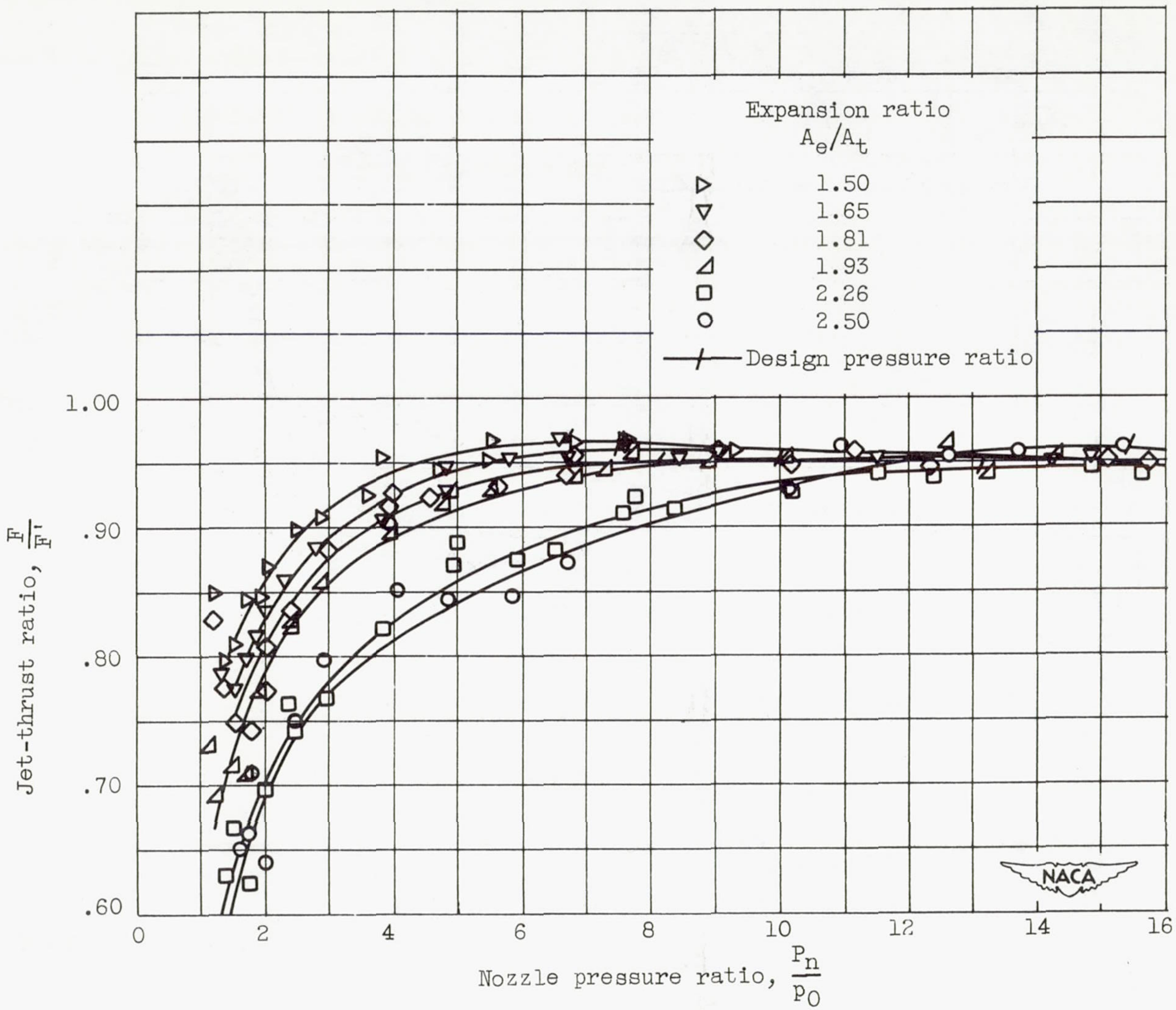
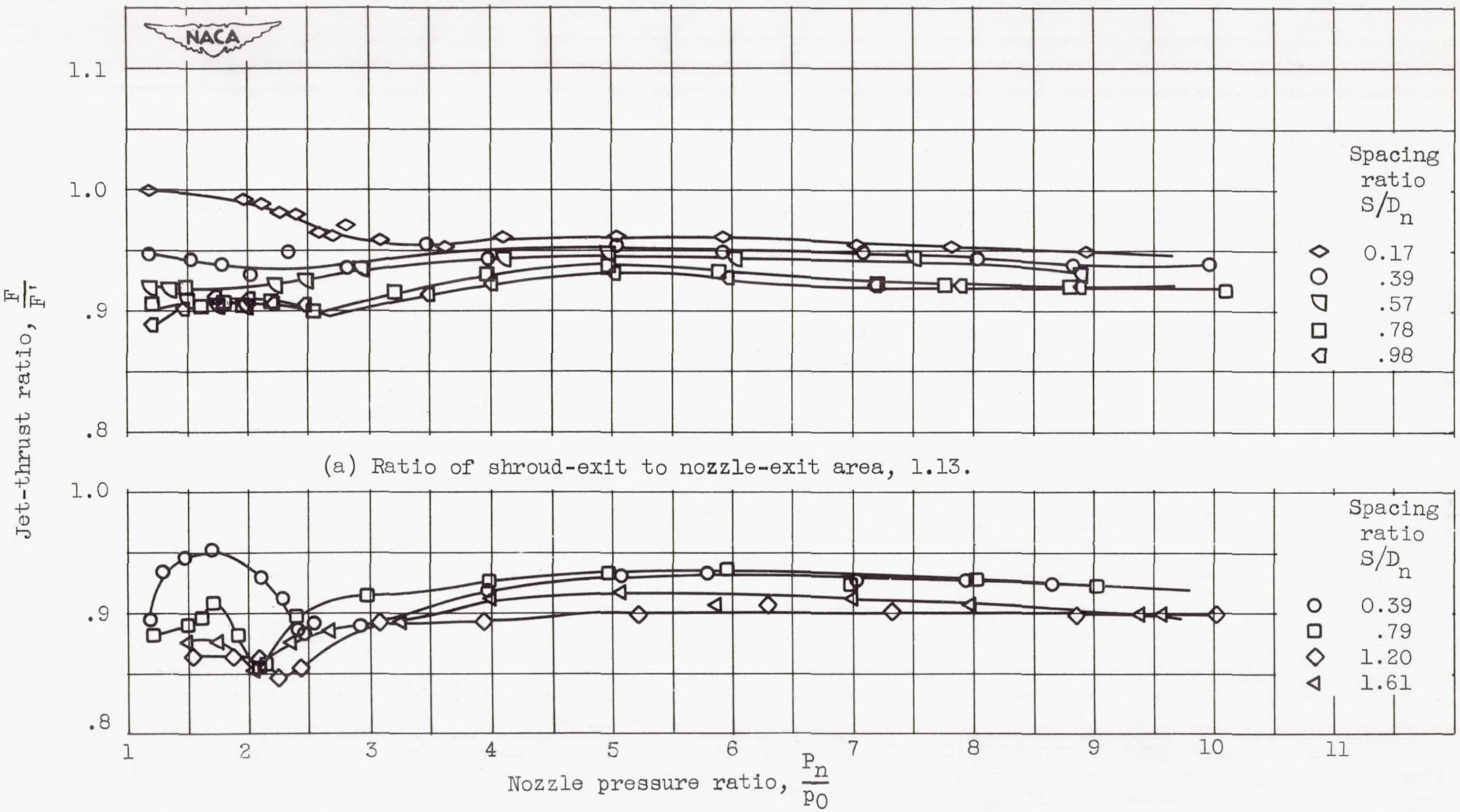
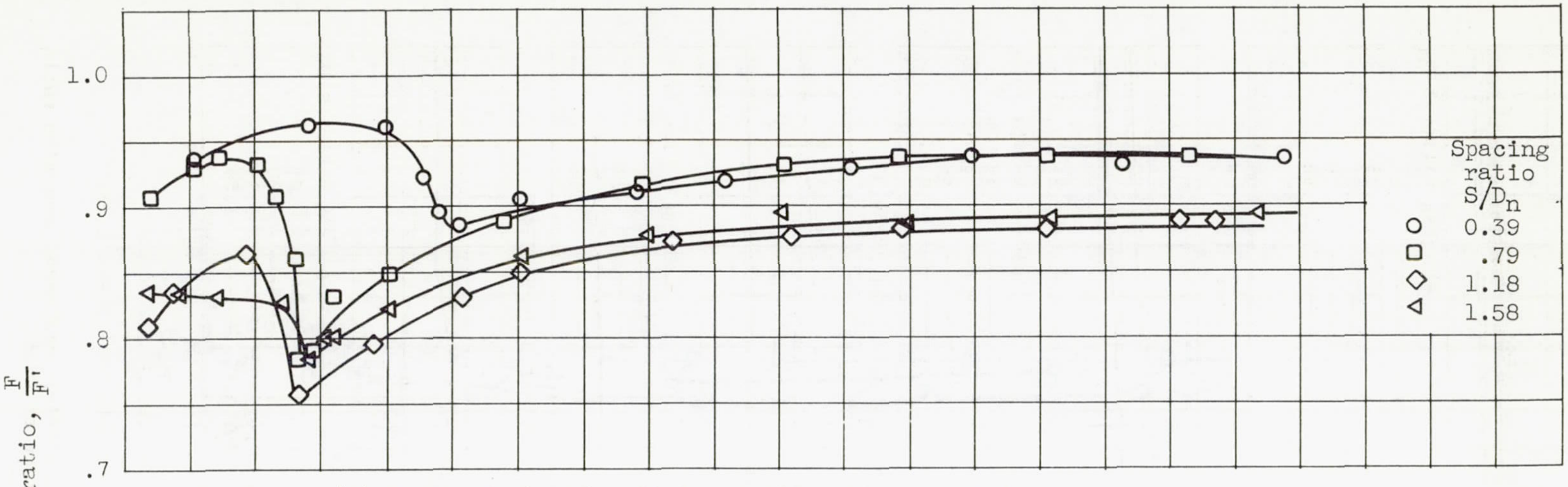


Figure 8. - Thrust characteristics of a variable-area plug-type convergent-divergent nozzle.

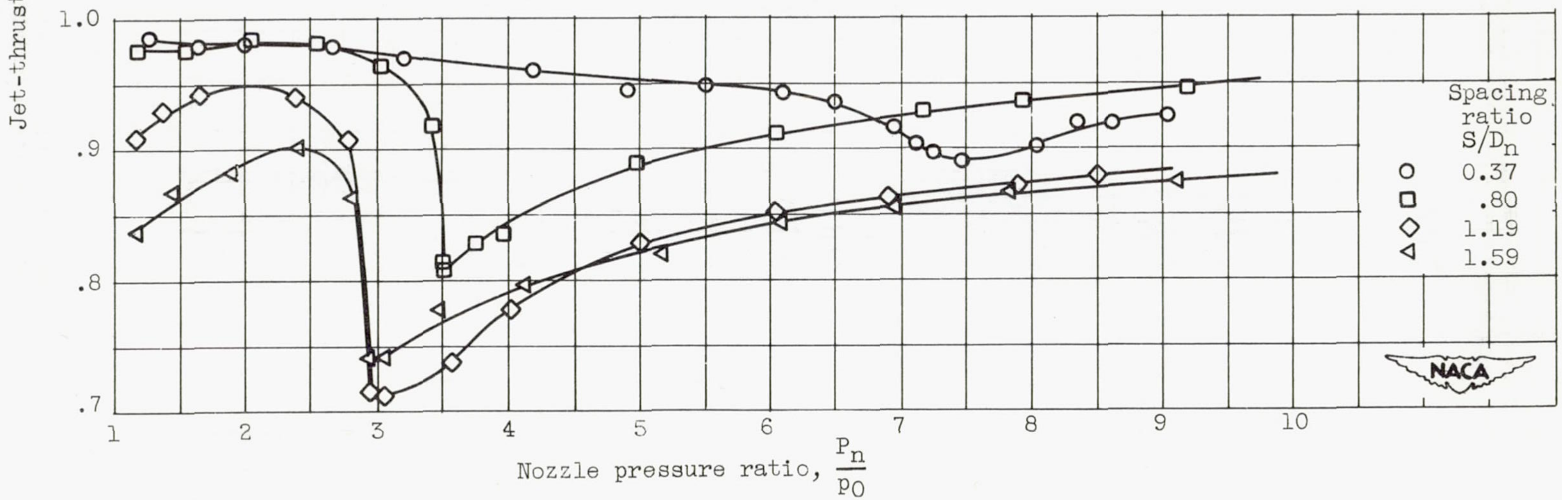


(b) Ratio of shroud-exit to nozzle-exit area, 1.21.

Figure 9. - Thrust characteristics of several ejector configurations with no secondary flow.

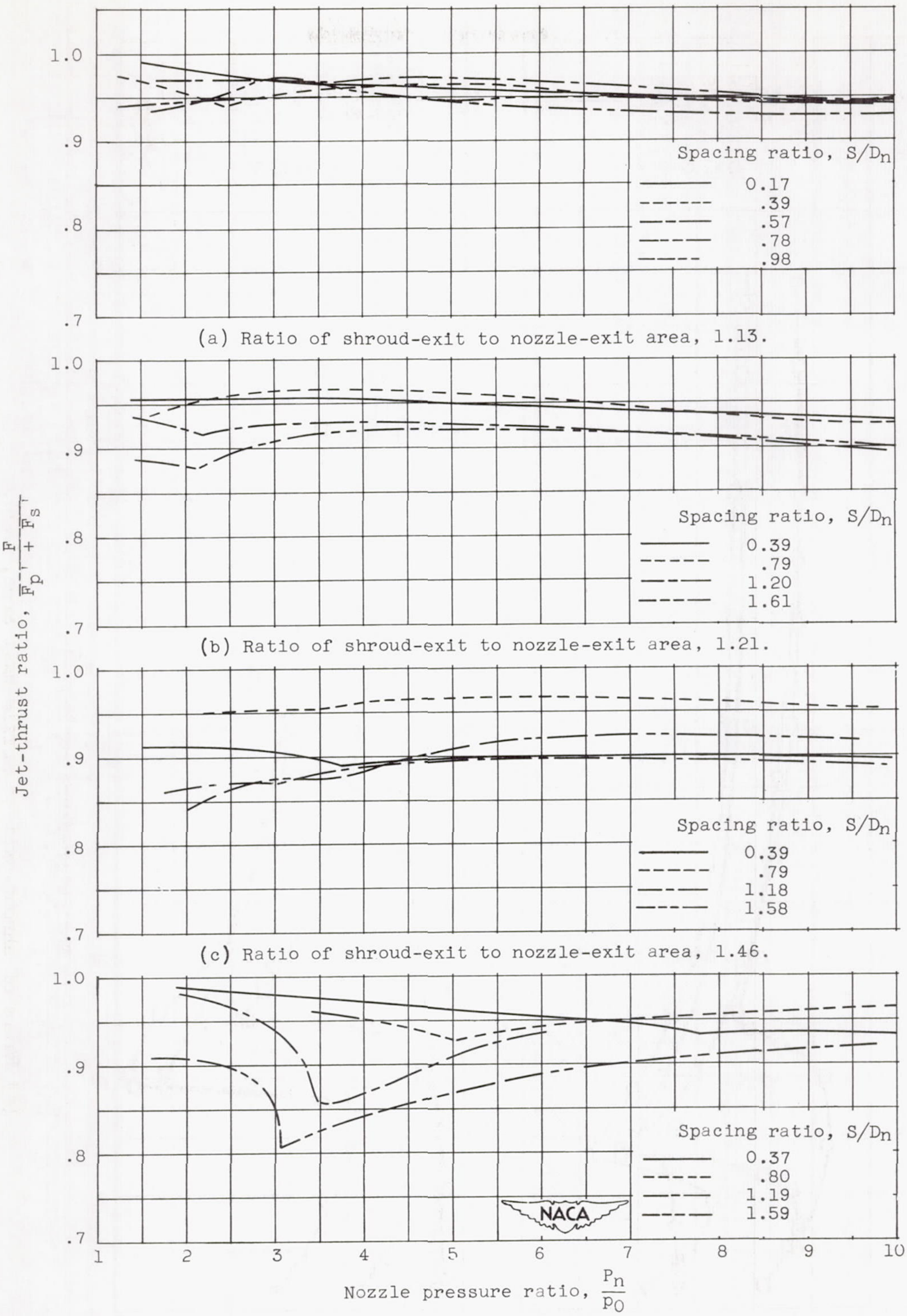


(c) Ratio of shroud-exit to nozzle-exit area, 1.46.



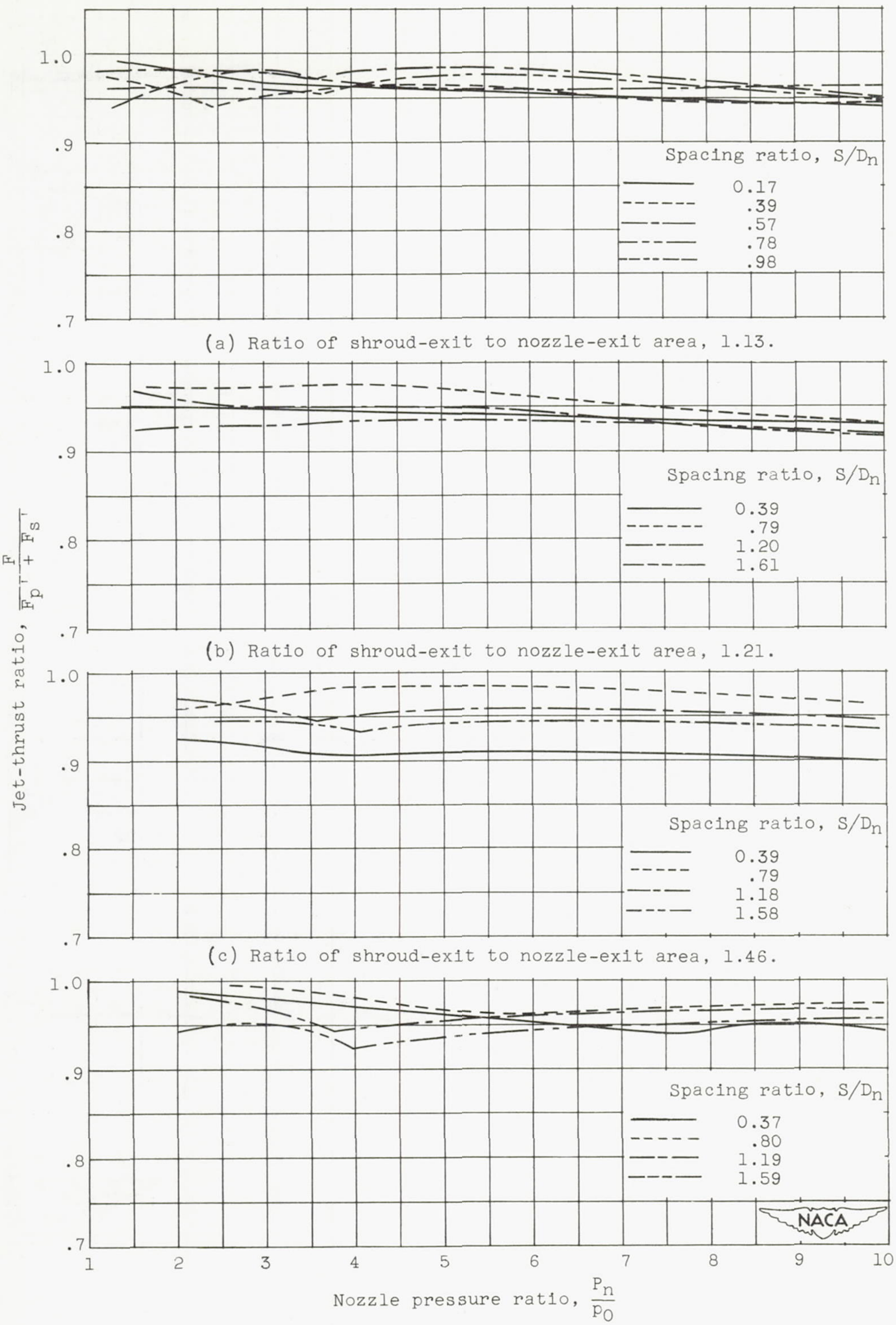
(d) Ratio of shroud-exit to nozzle-exit area, 1.96.

Figure 9. - Concluded. Thrust characteristics of several ejector configurations with no secondary flow.



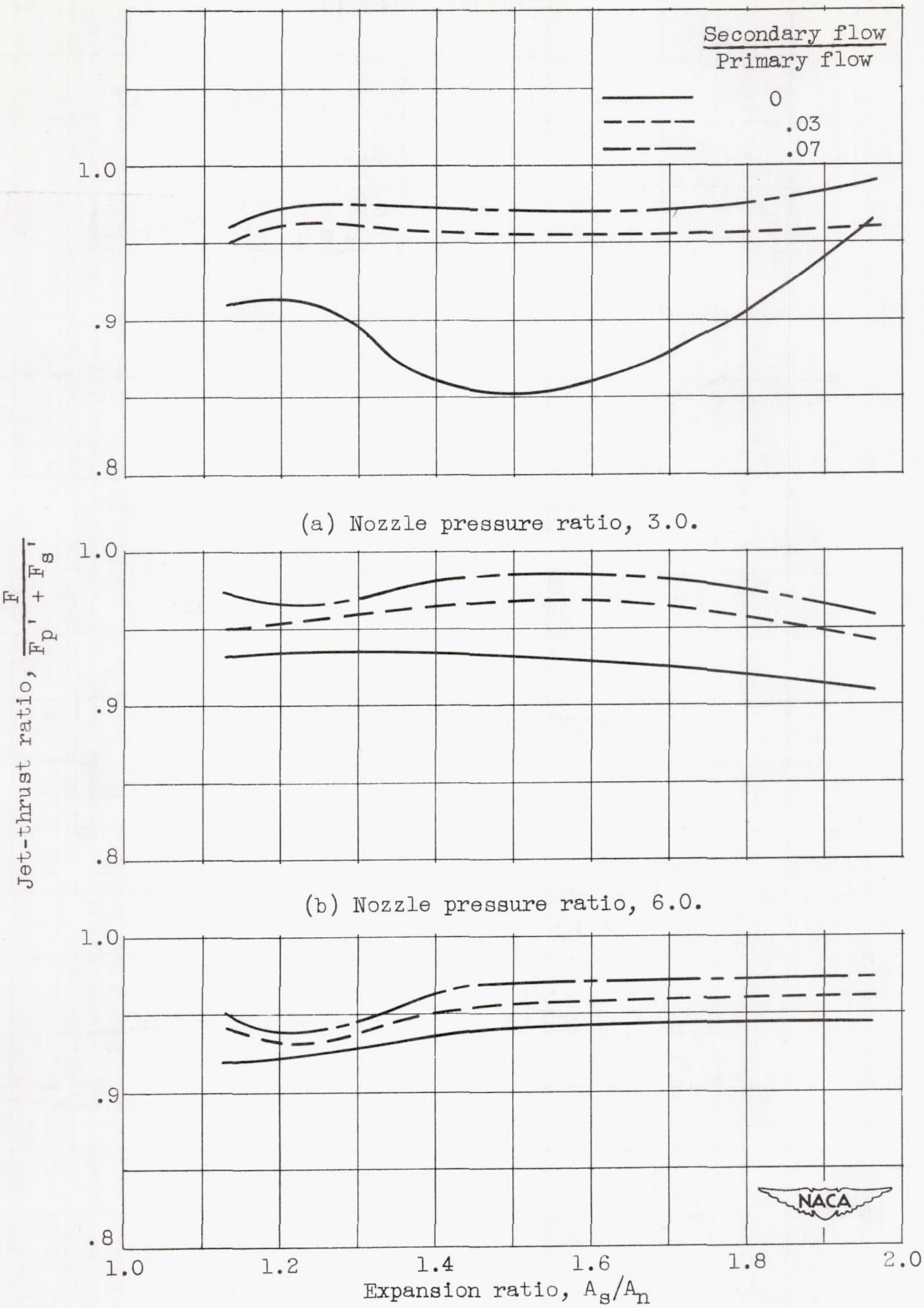
(d) Ratio of shroud-exit to nozzle-exit area, 1.96.

Figure 10. - Thrust characteristics of several ejector configurations with ratio of secondary-to-primary flow of 0.03.



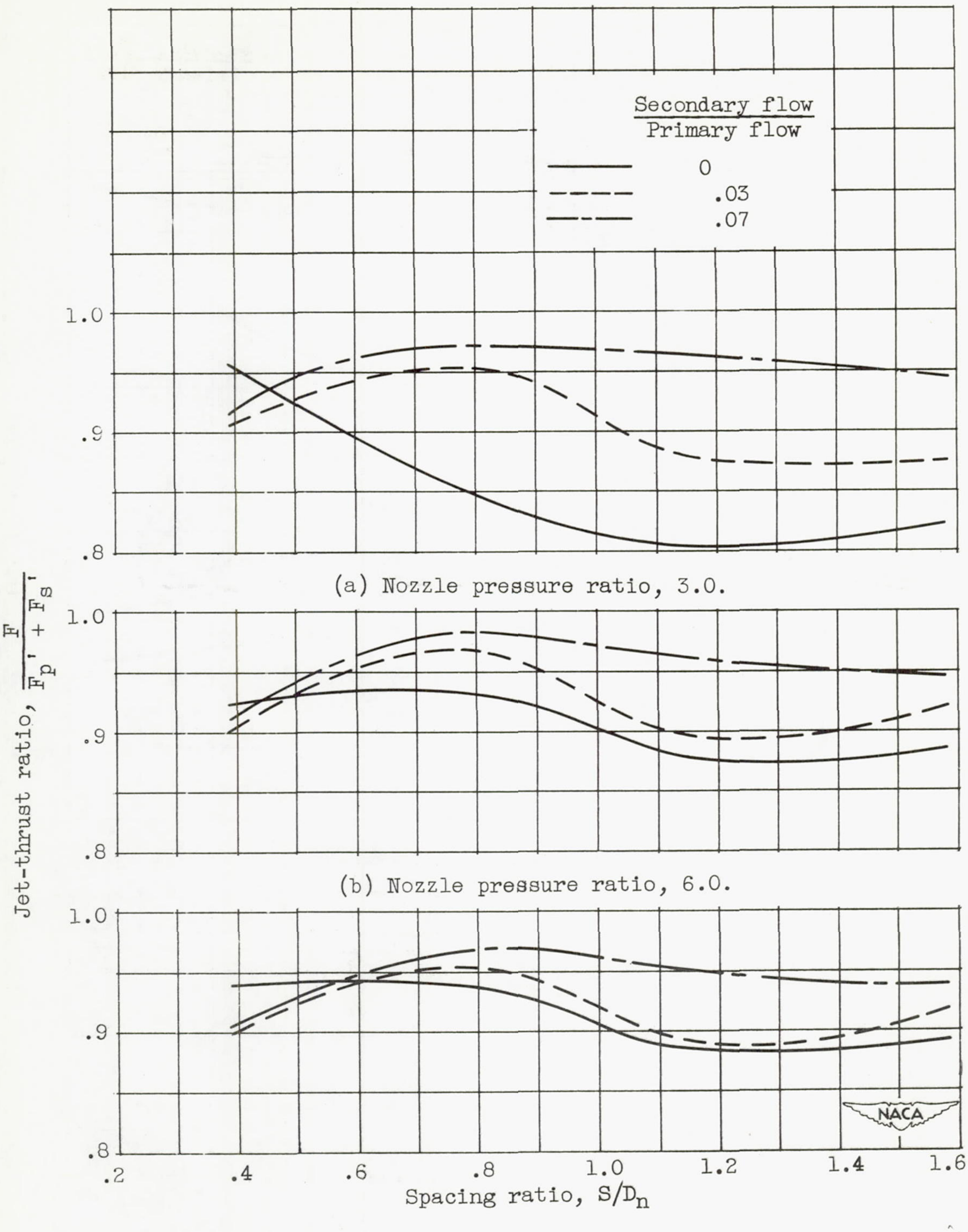
(d) Ratio of shroud-exit to nozzle-exit area, 1.96.

Figure 11. - Thrust characteristics of several ejector configurations with ratio of secondary-to-primary flow of 0.07.



(c) Nozzle pressure ratio, 9.0.

Figure 12. - Effect of expansion ratio on ejector thrust characteristics. Spacing ratio, 0.8.



(c) Nozzle pressure ratio, 9.0.

Figure 13. - Effect of spacing ratio on ejector thrust characteristics. Expansion ratio, 1.46.

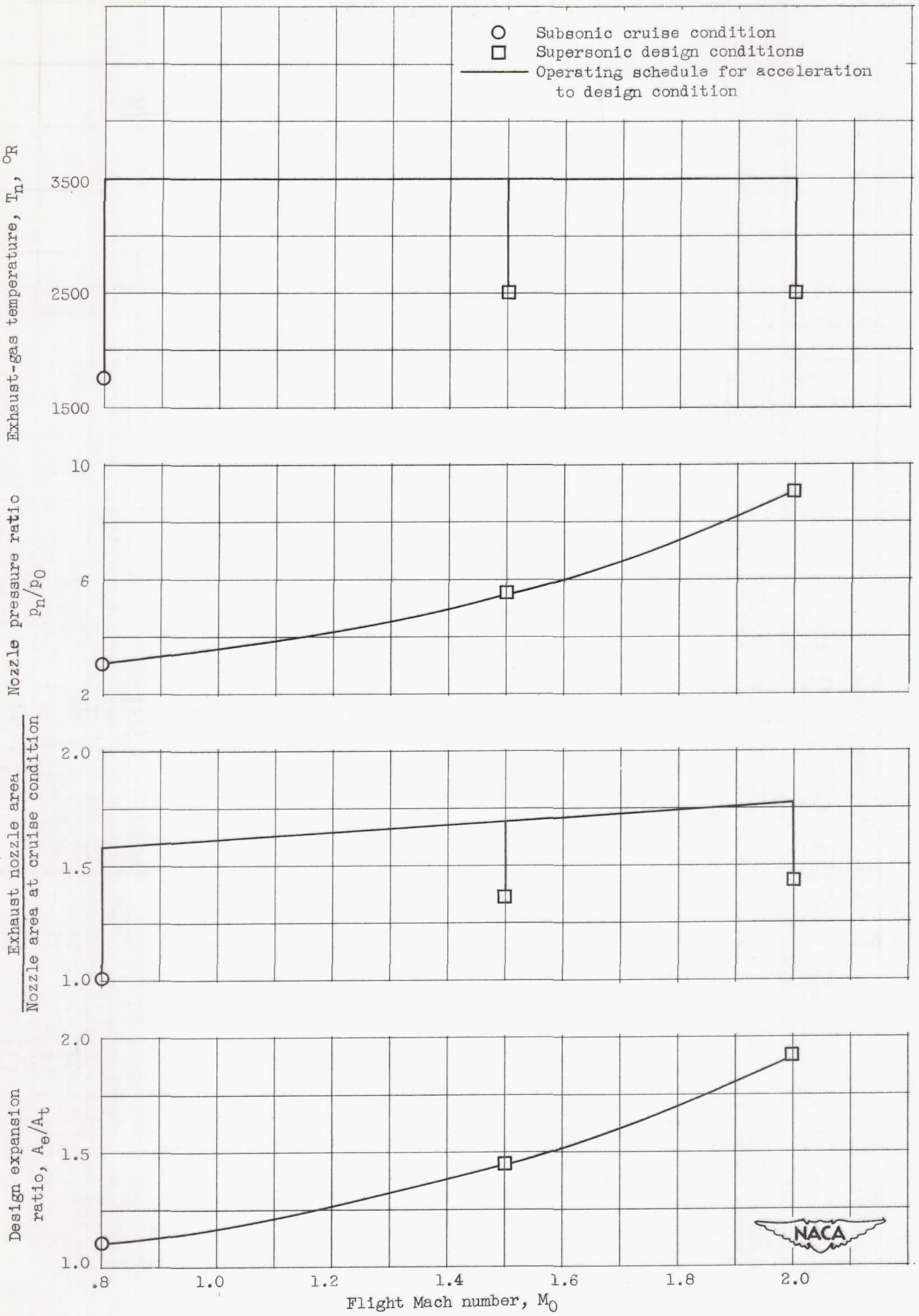
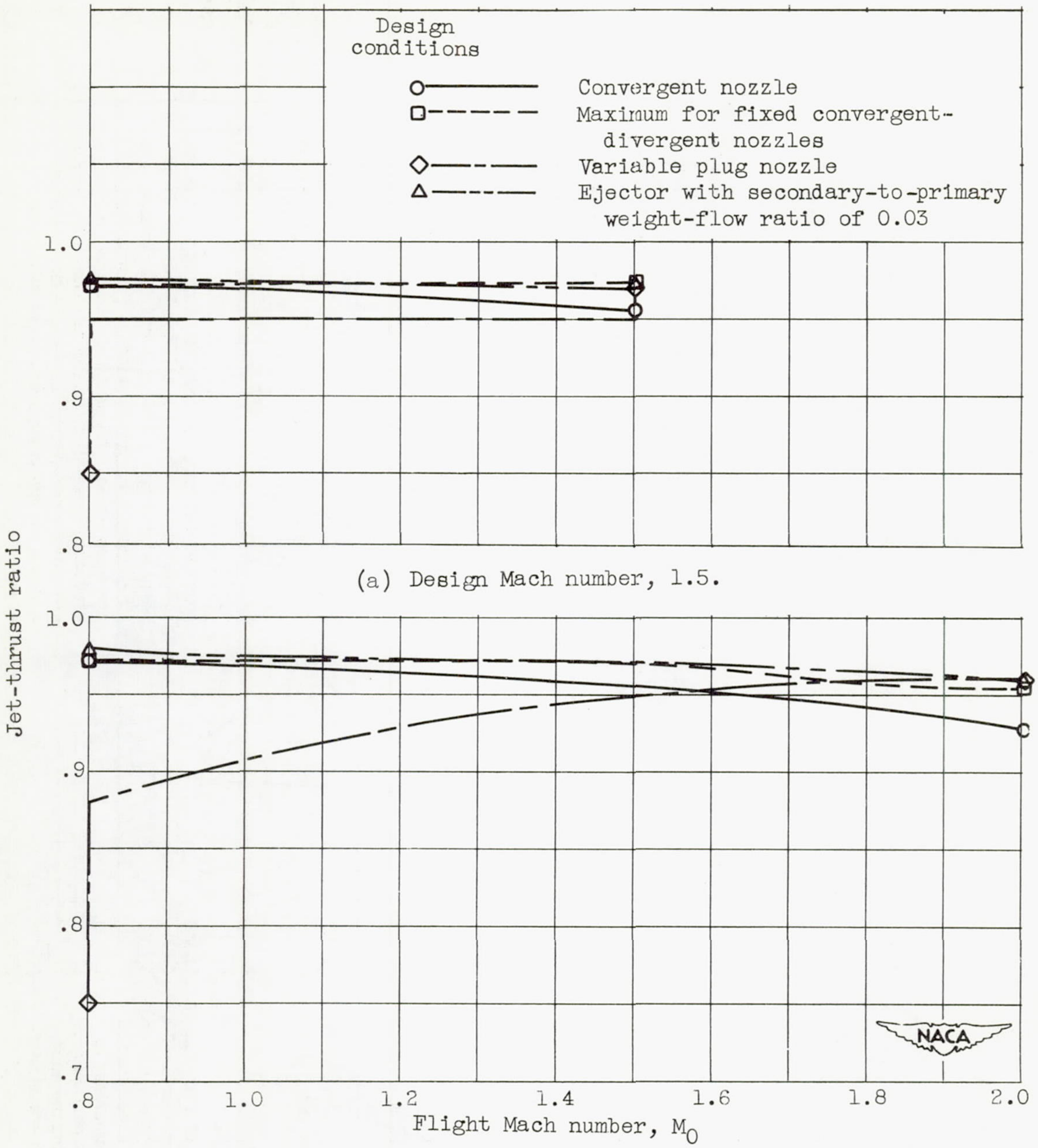


Figure 14. - Selected nozzle operating schedule for typical supersonic turbojet aircraft.



(b) Design Mach number, 2.0.

Figure 15. - Comparison of thrust characteristics for several jet-exit configurations when matched to schedule of typical supersonic turbojet aircraft.